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Discussions for linking the Nature of Science (NOS) with Scientific Inquiry

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Abstract: Even though the importance of the nature of science (NOS) and scientific inquiry in science learning have been emphasized by many science educators and science curriculums, the link between the NOS and scientific inquiry has not been discussed sufficiently. In this article, I discussed that various aspects of NOS are already embedded in defining and characterizing the authentic scientific inquiry and that we need to have special concern about how the NOS should be treated and interpreted when introducing it into scientific inquiry. And I summarized two approaches to teach the NOS and scientific inquiry; teaching the NOS through scientific inquiry and teaching scientific inquiry through the NOS. Finally, some next studies based on this article are introduced.

Key words: the nature of science, scientific inquiry, teaching approaches, authentic way for conducting scientific inquiry.

I. Introduction

This article is to discuss theoretically about the relationship between the nature of science (NOS) and scientific inquiry.

In fact, the importance of the NOS in teaching science have emphasized in many science educators (Bell and Lederman, 2003; Hand et al., 1999; Lederman, 1999; Matthews, 1994; Osborne et al., 2003; Vhurumuku et al., 2006) and science curriculums (AAAS, 1994; McComas and Olson, 1998; NRC, 2000; NSTA, 2000). Many researches about the various characteristics and practical contents of the NOS can be found in the literature (Abd-El-Khalick and Lederman, 2000; Akerson, et al., 2006; Lederman et al., 2002; Park, 2007; Sandoval, 2005). And also, scientific inquiry has also been regarded as an essential factor in teaching science. However, it has been also noted that the link between the NOS and scientific inquiry is not discussed in more detail (Lederman, 1998; Matthews, 1998; Sandoval, 2005; Schwartz et al., 2004).

In this article, at first, I discuss which aspects of the NOS are embedded basically in scientific inquiry, and then what aspects should be concerned especially for introducing the NOS in conducting scientific inquiry. Finally, I classified two teaching approaches for the NOS and scientific inquiry into teaching the NOS through scientific inquiry and teaching scientific inquiry through the NOS.

II. NOS embedded in scientific inquiry

Scientific inquiry generally refers to a process of observing natural phenomena, finding features or regularities from observations, asking questions, suggesting a hypothesis as a tentative answer to the question, designing an experiment to test a hypothesis, obtaining data, analyzing and interpreting the data, drawing conclusions, communicating the conclusions, applying conclusions to other situations, and so on. (Krajcik et al., 1998; Sandoval, 2005; White and Fredericksen, 1998).

In defining and describing the scientific inquiry, we can find that various aspects of the NOS are involved - such as, the nature of the scientific inquiry process, the epistemology of scientific knowledge, social interactions in a scientific community and so on. For instance, Hofstein and Lunetta (2004) noted that the meaning of authentic scientific inquiry involves what students *sense about the spirit of science* as well as what they investigate in the natural

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world. And Bybee (2000) asserted that doing scientific inquiry involves that students should *understand what scientific inquiry is* as well as should be able to use scientific inquiry skills. Therefore we can infer that understanding the NOS is an important condition for conducting scientific inquiry in more authentic way. For instance, when being asked to suggest scientific hypotheses, students just guess what will happen without thinking about causal relationships. This means that they do not understand the fact that a scientific hypothesis is a tentative causal explanation rather than a simple guess. If students recognize that similarity-based reasoning, such as abduction or analogy, can be used effectively to generate a scientific hypothesis (Park, 2006), this kind of understanding regarding the nature of scientific inquiry may encourage them to perform inquiry activity in more authentic way.

Toth et al. (2002) noted that the scientific inquiry approach applied in their study was authentic because (a) a solution of inquiry was not pre-determined; (b) students were encouraged to develop *different viewpoints* as if they were scientists; (c) students chose and used *multiple data* including anomalous and uncertain ones; and (d) students evaluated *multiple sources of evidence* with *multiple viewpoints.* According to them, aspects of the NOS, such as the multiplicity of scientific claims and evidence, should be embedded in authentic scientific inquiry. NRC (1996) also said that inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of *alternative explanations* (NRC, 1996, p. 23).

In many research publications, researchers have stressed that awareness of social aspects in scientific research is one of the important conditions for authentic scientific inquiry. For instance, Schwartz et al. (2004) described scientific inquiry as the scientific enterprise and processes through which scientific knowledge is constructed, and as involving the conventions and *ethics* during the development, *acceptance*, and utility of scientific knowledge. This means that the social aspects of the NOS, such as ethics and acceptance by the scientific community, are embedded in scientific inquiry itself. Lee and Songer (2003) cited Brown et al.'s description of authentic scientific inquiry as a social activity through which scientific products are constructed through *negotiations* among scientists. Rudolph (2005) also pointed out that science, different from technology, cannot be pure such that intellectual work of science is restricted to an elite group of experts and happens in isolation from the needs and concerns of society. Rudolph concluded that science is *intrinsically embedded in society* (Collins and Pinch, 1998; Pickering, 1995). Therefore Rudolph (2005) emphasized that scientific inquiry should be designed for students to see how even pure scientific questions emerge from human needs and social conditions and not from just pure curiosity. To give consideration to social experiences during an inquiry activity, White and Frederiksen (1998) encouraged students to conduct their inquiry within a '*research community*' in which they reviewed and assessed the processes of their inquiry process, products they obtained, and reflected on their various perspectives regarding them.

In summary, in the many researchers' and teachers' efforts to teach scientific inquiry in a more authentic way, as a condition for, constraint of, or as a facilitator for authentic scientific inquiry, they have emphasized understanding various aspects of the NOS.

Ⅲ. Discussions for introducing the NOS into scientific inquiry

Even thought the NOS is an important factor in conducting scientific inquiry, we need to have special concern when introducing the NOS into teaching scientific inquiry. In this section, several problems regarding introducing the NOS into scientific inquiry are discussed: theory ladenness of observation, tentativeness of scientific knowledge, multi-processes of scientific inquiry, limitation of induction, and logical impossibility of experimental confirmation of scientific knowledge.

Theory-ladenness of observation: Let us imagine the learning situation in which students try to find any regularities from their observations in the laboratory. In this case, students need to focus on common features from their observations. However, theory-laden observation indicates that there cannot be objective observation and all observations may differ by the influence of an observer's background knowledge. Therefore, students' activity to try to find any regularity from their observations seems to contradict the nature of scientific observation.

What is required is to re-consider the meaning of theory-laden observation when teaching scientific inquiry in schools. In fact, the purposes of scientific observation by students vary according to the purposes of the scientific inquiry. For instance, students can make an observation to understand certain phenomena or events, to describe any characteristics of nature as it is, or to give evidence to their predictions.

If the purpose of scientific inquiry is to understand the subatomic particles' collisions through the observation of photocopy of a cloud chamber, active theory-laden observation using appropriate scientific knowledge including momentum, electric charge, or magnetic field is recommended.

But, when describing the characteristics of nature, for instance, when observing the temperature change of heated water, students need to make more objective observations in true light rather than any rash interpretation based on theories. In this case, *less* theory-laden observation needs to be encouraged. With regard to this second aspect, Duhem, (Duhem, 1974, p. 145), asserts that, "(among two kind of observations) in the first place, it consists in the observation of certain facts; in order to make this observation it suffices for you to be attentive and alert enough with your senses. It is not necessary to know physics."

Moreover, when comparing observation with predictions, someone may distort their observation toward what they predicted when the result differs from their prediction (Park & Kim, 2004) or sometimes an investigator may make a selective observation through which he/she is concerned about only observations confirming prediction and reject or disregard conflicting observations. This phenomenon may occur as a result of an observer's lack of awareness of the distinction between observation and theory (Kuhn et al., 1988; Park and Pak, 1997). In this case, '*theory-detached*' observation needs to be encouraged by the teacher. Here, '*theory-detached*' does not mean theory-free because any theories are subject to being embedded in observation. What theory-detached means is that the intended effort trying to differentiate evidence from theory is necessary for seeing the phenomena separately from the observers' prediction. That is, the observation is not the prediction (or theory) itself but the evidence which can confirm or falsify the prediction.

As a result, even though we admit the fact that all scientific observation is inherently theory-laden, when teaching scientific inquiry using observation in schools, we need to encourage active theory-laden observation, less theory-laden observation, or sometimes, theory-detached observation, according to the goal of scientific inquiry.

Tentativeness of scientific knowledge: Rudolph (2005) criticized that almost all science textbooks describe science as consisting of reliable and objective knowledge. To correct students' mis-belief that scientific knowledge indicates absolute truth, educators have recommended the history of science to describe developmental process of scientific knowledge, such as, the development of atomic theory from Aristotle to Bohr or heat concepts from caloric theory to molecular kinetic theory. Here, following questions can be asked: Do students need to understand the past theory which was judged as wrong nowadays? If the scientific knowledge does not tell the truth about the nature at all, how can we encourage students to use scientific knowledge to understand nature?

The first question is worth mentioning because there is too much that students should learn at schools. Moreover understating wrong knowledge from the past is not necessarily easy to them. And also, if students knew already which ideas were wrong, then they did not show empathy for these past wrong ideas. So, the historical approach does not always influence students' understanding the NOS favorably (Khishfe and Abd-El-Khalick, 2002). Therefore, in addition to the approach using the history of science, we need to develop the alternative approach to help students recognize the tentativeness of scientific knowledge. In fact, all scientific knowledge is constructed based on various conditions including ideal conditions (Song et al., 2001), and surrounded by a protective belt consisting of auxiliary hypotheses and assumptions (Lakatos, 1994). For instance, two objects fall equally irrespective of the mass of these objects near the surface of the earth only when there is no air resistance, when the objects fall at the exactly same height, when the gravitational field is constant, and also when the inertial masses of the objects are the same as the gravitational masses. Therefore, students should be instructed to realize that there are hidden conditions and auxiliary assumptions and that scientific knowledge can be varied according to the change of conditions and assumptions (Park et al., 2001). Then, students can be aware of the tentative nature of the scientific knowledge which they learn at schools currently. Of course, considering the effect of air resistance or other conditions on falling objects is not necessarily easy work. However, the point is to help students realize that scientific knowledge has limitations inherently; therefore, it is subject to being tentative. Instead of making students analyze rigorously the effect of changes according to the changes of conditions and assumptions, the simple observation of a demonstration of falling objects with air resistance using a simulation program can be utilized for middle or high school students.

The second question is closely related to the attitude to science. That is, if students realize that Ohm's Law is tentative therefore it does not tell the truth at all, and then application of this law to various electric circuit problems may be shown as not trustful to them. Then various scientific problems solving that can be perceived as being meaningless to them. In this case, if students understand that scientific knowledge involves various initial/ideal conditions and auxiliary assumptions, then students can easily feel that scientific knowledge is *correct* only when those conditions and auxiliary assumptions are fulfilled. This means, "Scientific knowledge A is correct under the condition B and assumption C and so on." As a result, students can understand that the tentativeness does not mean incorrectness of scientific knowledge but *correctness of it under given circumstances.*

Multi-processes of scientific inquiry: In actual scientific research, scientific inquiry usually proceeds along multiple paths, goes back to previous steps (non-linear process), and sometimes involves several repeated processes (cyclic process) (Park, Jang, and Kim, 2008). Therefore, it has been pointed out that a universal and simple algorithmic process of scientific inquiry may not be possible (Alters, 1997; Windschtl, 2004).

Then, our question is how we can present directions or guides for conducting scientific inquiry in a school context. It is well known that a step-by-step direction for conducting scientific inquiry has been criticized by its cook-style format and also by its wrong reflection of the NOS (e.g., the nature of complexity and diversity of scientific inquiry). So, some researchers have emphasized an open-type inquiry activity where the inquiry questions, procedures, and results are not pre-determined (e.g., Zion, et al., 2004). Open inquiry is appropriate for project-type inquiry activity requiring a long-term period of time. However, it is not easy to apply open inquiry emphasizing multiplicity of steps to ordinary school laboratory activities designed only for one or two hours of duration. Therefore, we need to develop special strategies to reflect the nature of complexity and diversity of scientific research into short-term scientific inquiry activities in schools. For instance, if we can prepare several different procedures for a given scientific inquiry theme, we can let students, working in groups, conduct different inquiry activities depending on the group they are in. During and after completion of these activities, these groups can compare each process and result, they can recognize the nature of complexity and diversity of scientific inquiry.

Limitation of induction: Induction is an inference of drawing universal law, a general pattern, or regularities from a limited number of observations. This process has been criticized because scientific knowledge through induction cannot be justified as a truth both empirically and logically (Chalmers, 1986). That is, even though students have made observations that water boils at 100℃ one hundred times, their conclusion that '*All* water boils *always* at 100℃' cannot be a truth. Accordingly, someone can insist that conclusions from many inquiry activities using induction, such as, drawing relationships between variables, finding a general pattern from observations, or classifying observations based on common features cannot be considered as confident results.

Then, we can ask, "When teaching scientific inquiry in schools, is the usage of induction indeed valid? Does not induction give any reliable and confidential scientific knowledge?" Here, it is required to help students understand that a conclusion from induction is not a logical consequence but a tentative claim using an investigator's inference. Scientific knowledge is not discovered from nature but invented by human's reasoning. Therefore, scientific knowledge needs additional verification through further research, and is subject to change according to further findings. However, induction is a very effective tool for inferring a general conclusion, even though it gives us the truth. This feature of induction is also closely related to the tentativeness of scientific knowledge. Because of this tentative characteristic, students need to get more observations under various different conditions and to explore the possibilities of conflicting with conclusions drawn by induction. Examples for teaching this aspect will be presented in a later section.

Impossibility of experimental confirmation of scientific knowledge: Many of us have claimed that scientific knowledge, especially scientific hypothesis, should be tested and confirmed through experimentation. Vhurumuku et al. (2006) also observed that students thought the role of experiment was verifying or showing that knowledge was correct. This means that any scientific knowledge passing an experimental test can be regarded as correct knowledge. However, according to Popper's assertion, as mentioned earlier, scientific knowledge cannot be confirmed experimentally. This lack of confirmation is because the logical structure of confirmation is based on '*affirmation of the consequent*' which cannot give a valid conclusion logically (Park et al., 2001). This feature gives confusion to science teachers who have taught that scientific knowledge is correct when experimental results are in accord with this knowledge.

To resolve this confusion, science teachers and students need to realize that obtaining experimental results which are in accord with theories means that the experimental results just support the theory; therefore, that the theory can be effectively used to explain, understand, and predict natural phenomena and other knowledge before the theory meets an anomaly. The theories supported by experiment are subject to being discarded or revised whenever these theories meet conflicting data and anomaly which cannot be explained. This characteristic is also closely related to the tentativeness of scientific knowledge.

Science teachers need to emphasize the role of experiment as falsifying theories as well as confirming them. But it is not easy to find an experiment whose goal is falsifying scientific knowledge in many science textbooks. It is also observed that students tend to predict experimental results confirming scientific knowledge when they are asked to design an experiment to test a given hypothesis (Park, 2003). For instance, students usually said, "If this result will be obtained, then we can confirm that this hypothesis is correct" rather than "If this result is drawn, then this hypothesis can be falsified." This tendency is stronger when they believe a given hypothesis is correct. Because this kind of attitude can have a negative effect on a student's fair evaluation of actual experimental results, it is required to encourage students to expect the possibility that theories can be falsified.

IV. Teaching the NOS and scientific inquiry

Based on the discussion about the relationship between the NOS and scientific inquiry, in this section, I will talk about two teaching approaches; teaching the NOS through scientific inquiry and teaching the scientific inquiry through the NOS.

The NOS through Scientific Inquiry: The first link between the NOS and scientific inquiry is to use scientific inquiry as a pedagogical tool for improving understanding of the NOS. Here, the primary goal is to improve students' understanding of the NOS by letting them conduct scientific inquiry.

Bianchini and Colburn (2000) used inquiry activity as a pedagogical tool for instructing students on the NOS. They identified six aspects of the NOS which could be used for instruction in an inquiry-oriented undergraduate course. Even though they did not examine the effect of instruction on improvement of understanding the NOS, their work showed which aspects of the NOS should be instructed in students' inquiry. For instance, when students were offered two different but reasonable test methods in a certain situation, they should be taught the fact that 'No one right way necessarily exists to solve a problem in science' as one aspect of the NOS.

Cartier and Stewart (2000), in a nine week inquiry based genetics course, let students construct a simple Mendelian model first. They then let the students apply the model to explain different natural phenomena and revise the model in response to anomalous data. To encourage this constructing-applying-refining process, students assembled in a small scientific community, such as a group or lab meeting. And they were asked to formulate and communicate ideas, to criticize and demand evidence for, and to offer alternative interpretations. This course was implemented with the objectives that students would understand the nature of scientific inquiry such as the iterative nature of inquiry, tentativeness of scientific knowledge, and dependence of a scientific model to empirical data as well as understand the theoretical background.

Zion et al. (2004) applied a new biology curriculum emphasizing open inquiry involving metacognitive skill such as reflection, self-control, and decision-making into an Israeli high school. Zion et al. observed that open inquiry could help students understand the nature of scientific processes. That is, students understood that the inquiry process were not linear but were subject to change and realized why inquiry skills such as controlling variables, repetition, and statistics were important when performing inquiry. White and Frederiksen (1998) also developed curriculum emphasizing metacogntive knowledge and skills through which students learned how scientific inquiry preceded. By applying it, thet observed that students' perceptions about the NOS changed. For instance, the number of students, who thought scientific theories were always true and mathematically abstract scientific concepts could not be understood by intuition, decreased.

There are studies announcing that scientific inquiry through apprenticeship can give students good understanding of the NOS (Bell et al., 2003; Richmond and Kurth, 1999). Richmond and Kurth (1999) , observed that grade 11 and 12 students, after a 7 weeks apprenticeship program, realized that scientific work needed a long period, was cumulative through the collaboration within scientific communities, and was subject to resulting in unexpected and puzzling situations. Bell et al. (2003) also, through an 8-week student apprenticeship program, observed that, even though the development of students' perceptions regarding the NOS was not so significant, few students changed their previous ideas such as the idea that the progression of scientific theories was linear. Students also realized that creativity played a seminal role in scientific research.

Schwartz et al. (2004) observed an enhancement of students' understanding of the NOS (about tentativeness, empirical basis, subjectivity, creativity, sociocultural embeddedness, observation and inference, laws and theories, and interdependence of these aspects) when students participated in an internship program which let them observe and participate in an actual project with scientists. This allowed the students to record the process of research, to respond to focused questions developed to help them connect the research experience to the aspects of the NOS, and to discuss and reflect on their experiences in relation to their views on the NOS.

But all efforts for improving the NOS through scientific inquiry have not been reported as successful. Abd-El-Khalick and Lederman (2000) found that an *implicit* approach utilizing inquiry activities without direct teaching or reflection about aspects of the NOS was relatively ineffective in improving science teachers' NOS understanding. That is, use of scientific inquiry alone as a pedagogical tool without any specific attention to the NOS does not guarantee an improvement of understanding of the NOS. Therefore, Abd-El-Khalick and Lederman (2000) recommended an *explicit* approach emphasizing explicitness and reflectiveness of the NOS when designing teaching plans for improving a learner's understanding of the NOS. Khishfe and Abd-El-Khalick (2002) also observed that, compared to an implicit teaching group, more sixth grade students in the explicit teaching group showed more developed views of aspects of the NOS. In the explicit approach, learners were encouraged to focus on aspects of the NOS through discussion, guided reflection, and specific questioning in the contexts of scientific inquiry activities and historical examples (Schwartz et al., 2004). More details about these two approaches - implicit and explicit - can be found in work of Abd-El-Khalick and Lederman (2000)

Scientific Inquiry through the NOS: Previous discussion about teaching the NOS through scientific inquiry focused mainly on pedagogical utilization of scientific inquiry to enhance students' understanding the NOS. However, 'doing scientific inquiry in a more authentic way' itself has intrinsic value in learning science.

The second link between the NOS and scientific inquiry is that the NOS should be a necessary condition for authentic scientific inquiry. Regarding this view, some studies showed that students who had a valid epistemological belief performed better in scientific inquiry (Bell and Linn, 2000; Sandoval and Reiser, 2004; Schauble et al., 1995; Toth et al., 2002). According to them, it has been claimed that understanding the NOS should help students do scientific inquiries better.

Schauble et al. (1995) observed that 6th grade students designed better experiments when they were encouraged to reason about the nature of experimentation during a period of three weeks instruction. In this instruction, students were taught the fact that negotiation between their existing knowledge and evidence collected by them was important and that the purpose of experiment was to revise or extend existing knowledge. These students were guided to communicate and debate results with peers.

Bell and Linn (2000) designed and implemented an argument building software application to promote students' knowledge integration and construction. This software facilitated their using and generating arguments supported by evidence through debate between rival theories. This program encouraged students to link their observations, experiences, and ideas to theories, and to use evidence in order to build their ideas with a more coherent view. In this study, Bell and Linn observed that students with a more sound understanding about the NOS, such as viewing science as dynamic, showed more and better argument construction.

Toth et al. (2002) let students reflect on their performing of scientific inquiry by using a checklist named 'inquiry rubrics' involving the nature of scientific inquiry methods. Using inquiry rubrics students were asked to determine whether they considered multiple hypotheses, used data not supporting as well as data supporting the suggested hypotheses, and so on. In this case, inquiry rubrics could guide students' inquiry activity and help them aware of the nature of scientific inquiry.

Sandoval and Reiser (2004) emphasized two epistemic aspects in making scientific explanation; they let students (a) articulate their explanation to be a form of coherent and causal accounts and (b) choose data as supporting evidence and then link this data to their claims. As a teaching aid, Sandoval and Reiser developed and used a computer program involving questions, explanations, evidence, and explanation guides suggesting possible contents of explanations and encouraging students to think about epistemic aspects in making explanation. Using this program, they could help students recognize the above mentioned aspects of the NOS. As a result, they observed that epistemic practices enhanced students' scientific inquiry in a more authentic way.

The meaning of 'better' performance of scientific inquiry: In teaching the 'NOS through scientific inquiry', scientific inquiry is used as a pedagogical tool for improving understanding the NOS; while in the approach of 'scientific inquiry through the NOS', the basic goal is the better performance of scientific inquiry. In the latter case, the NOS is a condition and accelerator for better scientific inquiry. Then, what is the meaning of 'better' scientific inquiry? According to previous works, better scientific inquiry may mean better use of inquiry process skills (Schauble et al., 1995), better scientific reasoning (Toth et al., 2002), better construction of sound scientific meaning, knowledge, or models (Bell and Linn, 2000; Sandoval and Reiser, 2004). Besides these, it may also mean better understanding of the goal of scientific inquiry or better co-working and communicating with peers.

Sometimes, above-mentioned aspects of better scientific inquiry are not independent but interlinked with each other. For instance, better use of inquiry skills may lead to better construction of scientific models. Also, for better use of scientific inquiry skills, a better understanding of the goal of scientific inquiry may be a prerequisite.

V. Summary and the Next Study

Basically, understanding the NOS itself can be a goal of science learning in schools. And also, we need to have concern about how understanding of the NOS can give effect on other aspects regarding to learning science, such as conceptual understanding, scientific inquiry, or attitude and interest on science. Especially, this study was initiated to relate the NOS with scientific inquiry because two of these have not been discussed sufficiently in the literature even though the understanding of the NOS is important in conducting scientific inquiry. Therefore, I tried to give answers to the following three questions; what features of the NOS are embedded in scientific inquiry? what should be considered to introduce the NOS into scientific inquiry? and how can we compare two approaches to teach the NOS and scientific inquiry?

Actually, I hope that this theoretical discussion about the link between the NOS and scientific inquiry can give us a rationale to perform the further studies. For instance, next study can be a suggestion of actual models for teaching scientific inquiry though the NOS. Then, this can help science teachers teach scientific inquiry in more authentic way because these activities will reflect the spirit of the NOS basically.

Inversely, we can have concern about teaching the NOS in the context of scientific inquiry. This also is not the area which has been studied sufficiently, because many materials for teaching the NOS have been developed in the context-free style. In fact, I already developed concrete worksheets for teaching NOS through scientific inquiry. In this worksheet, scientific concepts and scientific inquiry skills as well as elements of the NOS are identified in each worksheet. Currently, I am applying the developed teaching materials for the NOS through scientific inquiry to students; therefore, the result of it will be reported in further article.

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